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Progress Report for Contract

NAS8-98203

**Auroral, Polar Cap, and Polar Cusp Modeling and Data Analysis for the IMAGE Mission
and LENA Instrument**

Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center

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October, 2001

1. Description of Progress

A) LENA Work

One of the chief mysteries in the LENA perigee pass data is the lack of an apparent auroral oval in the images. Another is that in some cases ENA are seen from any direction near the Earth regardless of the latitude of the spacecraft. These facts lead one to ask a fundamental question: Is the instrument responding to ENA primarily? One possible way to get out of the 'ambiguity' of the data is to assume that at least part of the signal is produced by something other than ENA. The two main candidates for this 'something else' are UV light and energetic charged particles.

UV light could only effect the instrument when its fan shaped aperture points toward the source. The most intense of which will be the sun, with day glow being the second strongest and the auroral zone, the third. We can rule out UV light as a prime source of counts in the perigee pass data for the following reasons. 1) The perigee pass signal is different in form and much stronger than the sun pulse signal seen just before or just after perigee. 2) There is no indication of the auroral zone, which would produce at least two peaks in the counts versus spin phase curve. 3) Mike Colliers' analysis of the sun pulse signal shows that it varies with the flux of the solar wind and not with variations in the solar UV flux.

Charge particles that enter the aperture of the instrument and produce counts would show up when the instrument looks in the direction from which they come. In all of the data I am analyzing voltages were being applied to the collimators so that most charged particles should have been excluded from the instrument but this effect could still show up where the flux of energetic particles is high enough. The most likely place would be in the auroral zone where energetic electrons and protons precipitate. If these particles are producing counts then they should be seen when the instrument looks in and near the zenith direction. In nearly all of the perigee passes the zenith direction is devoid of counts.

The relationship between LENA perigee flux intensities and measures of magnetic and solar activity, and instrument state

Over the last two months I have finished processing all of the useable perigee pass data between the dates of 10 June and 29 August 2000. The data set consists of 99 perigee passes. I have prepared blow up spectrograms of each pass correcting the data by removing background counts.

The first thing shown here is a plot for the three-month interval that nicely summarizes many of the issues found in this analysis. Figure 1 is a plot of the Ap history for the three-month interval of June, July and August 2000. Over plotted in each month's panel is the total count intensity for each perigee pass. This quantity is found by summing all of the valid H and O counts (background subtracted) for the 10 to 18 images bracketing each pass.

The passes displayed in figure 1 can be divided into one of three groups. The first group consists of passes whose variation in total intensity tracks well the variation in magnetic activity. This set consists of perigee passes from June 10th to June 28th and July 26th to July 30th. The second group consists of the passes between 29 June and 9 July 2000 and is characterized by an almost complete lack of correlation with magnetic activity. The variations seen in the total intensity for this set suggests that the instrument was switching between two different operating states almost from one orbit to the next. There is however no evidence in the state tables for the dates in question to show that that was the case.

The last group of passes consists of those that occurred between 31 July and 29 August 2000. Here again there is a lack of correlation between total intensity and magnetic activity but in

addition, the total intensity of each pass is on average larger than the other two groups. The first perigee pass in this group occurred near 0920 UT on the 31st of July and had a total intensity of over 10^5 counts, the most intense of the entire data set. The behavior during the first three days of this set suggests that the instrument was made very sensitive on the 31st and that over the next two days the gain was turned down. (There is a significant up swing in magnetic activity on the 31st to a Kp of 5+ but this occurs after the perigee pass.) There were a large number of changes made in the state of the instrument on the 31st prior to the perigee pass on that date.

Below is a table that summarizes the state of the instrument for the three perigee pass groups described above. As far as I can tell there was no change in how the instrument was operated between the 10 June and 30 July 2000. Nearly all instrument settings were maintained constant during this interval with the exception of the stop MCP voltage which was turned down during outbound radiation belt passage. The voltage reduction occurred in a single step usually prior to the spacecraft reaching perigee. This instrument state change is reflected in the data by reduced image intensity and a drop in the O/H ratio. Since there was apparently no change in the way the instrument was operated between perigee pass group 1 and 2 the odd behavior of the data between June 29th and July 9th is still a mystery.

There appears to be hope in explaining why the data from the August perigee passes differs so much from the June and July passes. For one thing the collimator voltages were higher (96 versus 86), the optics HVPS was enabled and set to 128 and flight software version 1 replaced version 24. Another difference was the way radiation belt passages were handled in August versus the earlier months. For one thing the minimum value was higher (131 versus 128) and it varied over the course of the month. For example, between August 2nd and August 19th the minimum was 131 to 132 but after August 19th it ranged between 138 and 139. There is a noticeable increase in the overall intensity of the perigee passes starting on August 20th. For the bright perigee passes of July 31st and August 1st the minimum value of the stop MCP voltage was 138. Another difference between the June-July and August perigee passes is that the stop voltage reductions were often done in several steps rather than one. In many cases there would be 4 to 5 steps spread over about 30 minutes.

Perigee Pass Group	Dates	Start MCP	Stop MCP	Coll Pos	Coll Neg	Optics	Steer.	Start CFD	Stop CFD	FSW Ver.
1	June 10-28 July 10-30	144	128/144	86	86	disabled	0	2	6	24
2	June 29- July 9	144	128/144	86	86	disabled	0	2	6	24
3	July 31- Aug. 29	144	131-144	96	96	128	0	2	6	1

One way to test the hypothesis that the fluxes seen by LENA during perigee passes are produced by upflowing ions is to see how well the fluxes correlate with magnetic activity. To that end I have taken the total counts from 50 perigee pass from the June 10th to July 29th 2000 time interval (groups 1 and 2) and plotted them versus the concurrent value of Ap. (see figure 2) The correlation coefficient for this data set is 0.55, which is good but not fantastic.

The emission of ENA from the auroral and high latitude ionosphere depends on the flux of energetic ions (O^+ or H^+) and on the column abundance of atomic oxygen above the ion heating region. It is well known that the flux of energetic ions varies with magnetic and auroral zone activity. The column abundance of O in the high latitude thermosphere also varies with

magnetic activity but on longer time scales. For example, for the MSIS86 model to calculate an altitude profile of atomic oxygen one can input magnetic activity information for up to three days prior to the time of interest. It is also known from general circulation modeling results that when the high latitude ionosphere is stirred by the electric field imposed on the magnetosphere by the solar wind the neutral thermosphere is stirred as well. This leads to low densities on the dawn and dusk sides of the polar cap and high densities in the cusp and midnight auroral zone regions. Oft times higher densities extend across the polar cap in the noon-midnight direction. This means that all else being equal, the cusp and midnight auroral zone regions should be more prolific producers of ENA than the dusk and dawn auroral zones.

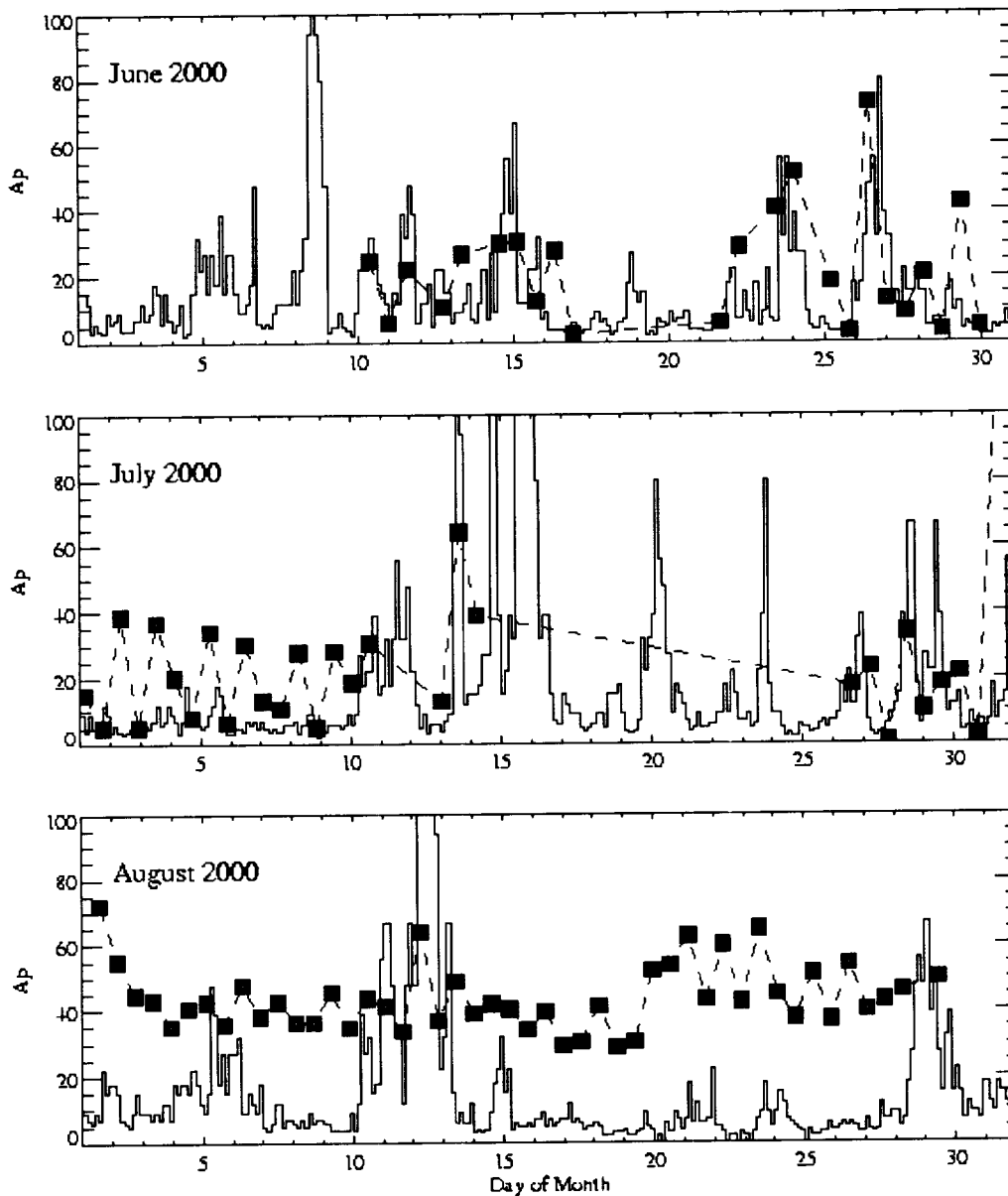


Figure 1. Ap history for the summer of 2000. Over plotted in each panel (filled squares) is the total intensity of the LENA counts in each perigee pass divided by 1000.

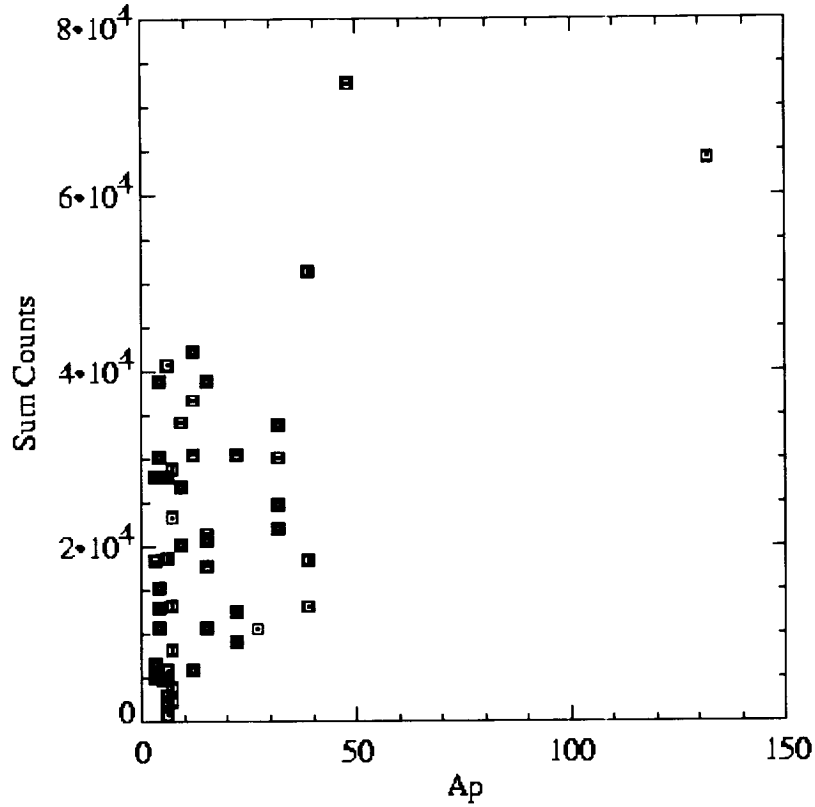


Figure 2. Plot of the total counts in each perigee pass versus the Ap index for the time of the pass.

Variations in the column abundance among these regions can be up to a factor of 5. Given that these conditions take longer to set up (then increases in the ion heating rate) and persist for a while after magnetic activity subsides it is reasonable to expect that ENA emissions might correlate also with magnetic activity from the recent past. To that end I test the 50 passes used in figure 2 with the Ap index from the previous four Ap intervals and got correlation coefficients of

Ap History	Correlation Coefficient Group 1	Correlation Coefficient Groups 1 + 2
Current Ap	0.61	0.55
Ap (-1)	0.39	0.34
Ap (-2)	0.39	0.34
Ap (-3)	0.06	0.08
Ap (-4)	0.19	0.20
Current Ap + Ap (-1)	0.56	0.49
Current Ap + Ap (-2)	0.67	0.57
Current Ap + Ap (-3)	0.51	0.45
Current Ap + Ap (-4)	0.56	0.49
Current Ap + Ap (-1) + Ap (-2)	0.59	0.51
Current Ap + Ap (-2) + Ap (-3)	0.53	0.46
Current Ap + Ap (-3) + Ap (-4)	0.45	0.40

0.34, 0.34, 0.08, 0.2 respectively. Clearly the perigee pass intensities correlate better with current activity than with past activity.

To get large perigee fluxes from heated ionospheric ions requires high heating rates at the time of the perigee pass as well as high O densities. This suggests that some combination of current and past magnetic activity may be required for maximum emissions. To that end I have calculated the correlation coefficient for the following cases listed in the following table. Here I use two data groups, those from perigee pass group 1 and those from group 1 and 2. This is done to see the effect that group 2 has on the correlations.

The highest correlation coefficient is for the case that uses the current A_p and the one from two A_p intervals back. The difference however is only a marginal improvement for the combined groups but is somewhat significant for group 1 alone.

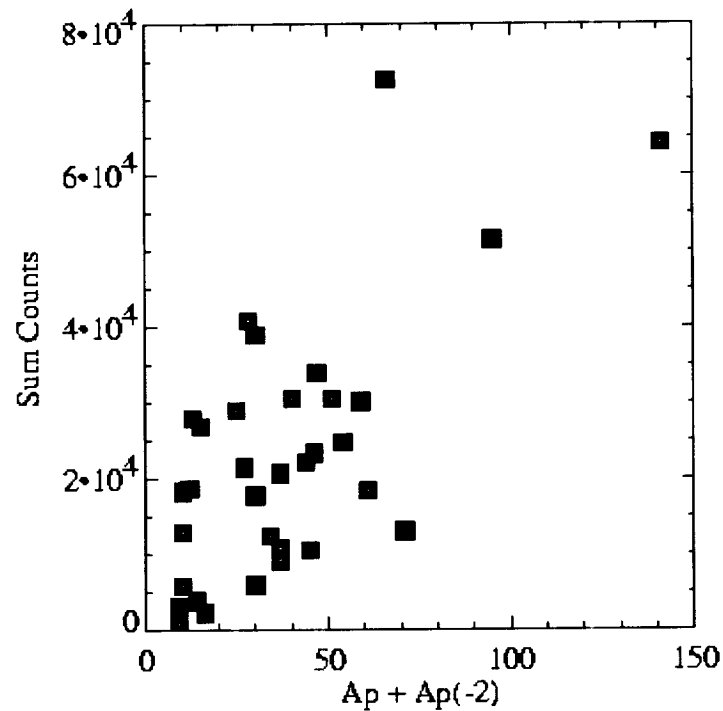


Figure 3. Plot of the total counts in each perigee pass in group 1 versus the A_p index for the time of the pass plus the A_p index from 6 hours past. This is the condition with the maximum correlation.

Because of the well know correlation between the flux of escaping suprathermal O⁺ ions and the level of solar activity I show in figure 4 below a plot similar to figure 1 except that A_p has been replaced with $F_{10.7}$. There seems to be little relationship between the perigee pass sum counts and solar activity. Note the overall decline in the sum counts between July 3 and July 9 when $F_{10.7}$ is increasing. Note also the interval from August 15th to the 25th when $F_{10.7}$ is decreasing but sum counts is increasing.

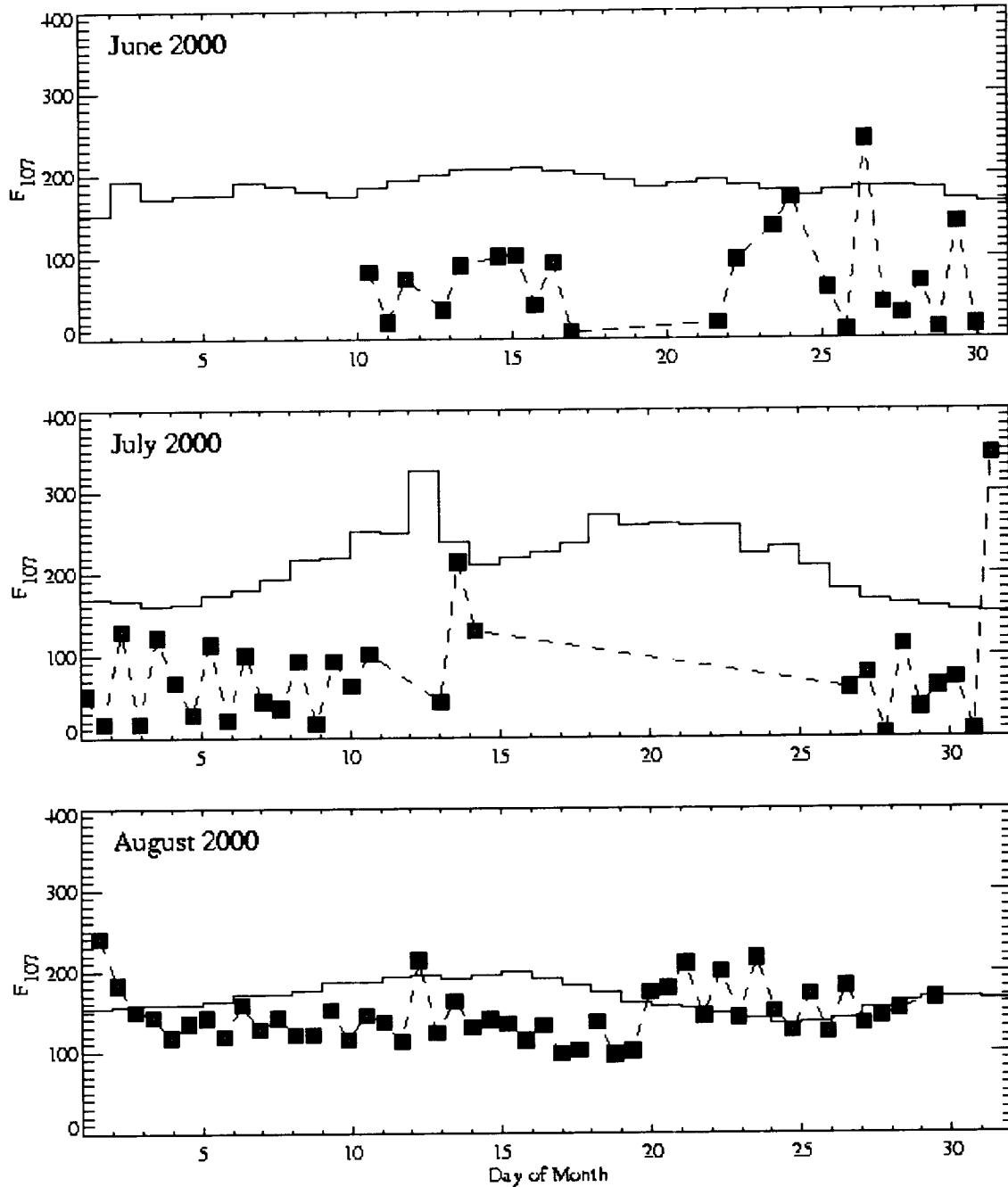


Figure 4. $F_{10.7}$ history for the summer of 2000. Over plotted in each panel (filled squares) is the total intensity of the LENA counts in each perigee pass divided by 300.

Individual Examples

Figure 5 below shows my typical blow up plot of the perigee data from July 31, 2000. In addition to the lines showing the trailing limb, nadir, approaching limb and ram directions, there is a series of diamonds showing the track of the sun's direction across the field of view. This perigee pass had the highest sum count total ($>10^5$) of any pass in the June-August 2000 interval.

The interesting thing about this pass is how the stop MCP voltage varied during the interval. According to the state logs this voltage was set at 144 up until 0917:01 when it was reduced to 138. It was increased to 143 at 0923:01 and 144 at 0927:00. So, for the most part the instrument retained a high sensitivity trough out the pass and into the radiation belts. There is a slight drop in the O/H ratio between 0912 and 0917 UT which could be due to the slight reduction in the stop MCP voltage although the timing doesn't quite line up with the values from the state table.

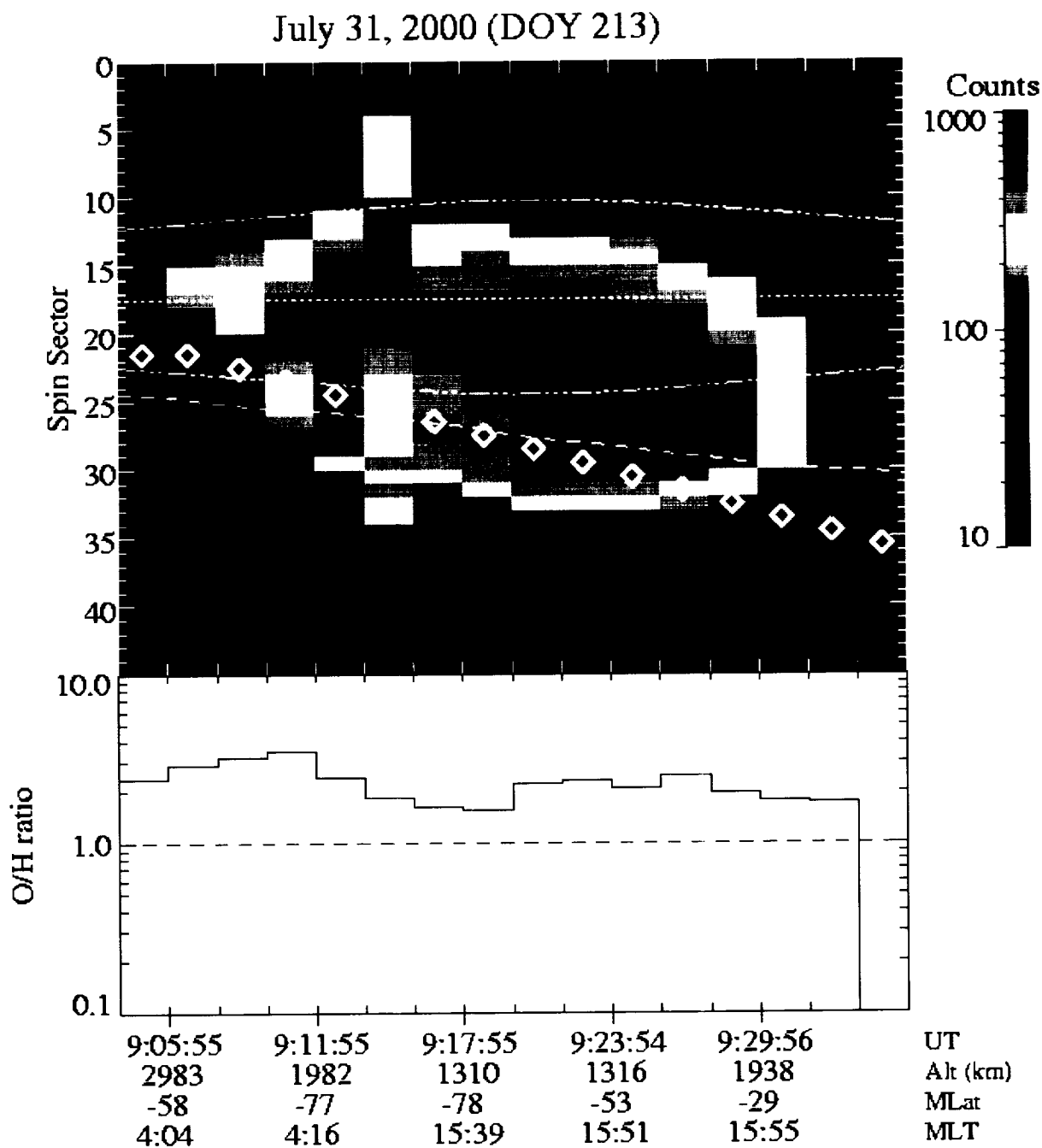


Figure 5. Perigee pass data for July 31, 2000.

Because of the different way in which the stop MCP voltage was varied during this perigee pass compared to previous passes, this case is likely the clearest example of how the low-altitude, low-energy ENA emissions look, unencumbered by instrument effects. When compared with my previous simulation results one can see that there is no apparent auroral oval. ENA emissions are seen coming from the Earth regardless of whether the spacecraft is over the polar cap, auroral zone, or low latitudes. There is an overall shift in the direction of peak emissions from the nadir direction to the approaching limb/ram direction.

The intensity of the images in this pass were collectively the most intense images seen on any other perigee pass I have looked at but there was nothing particularly interesting happening that

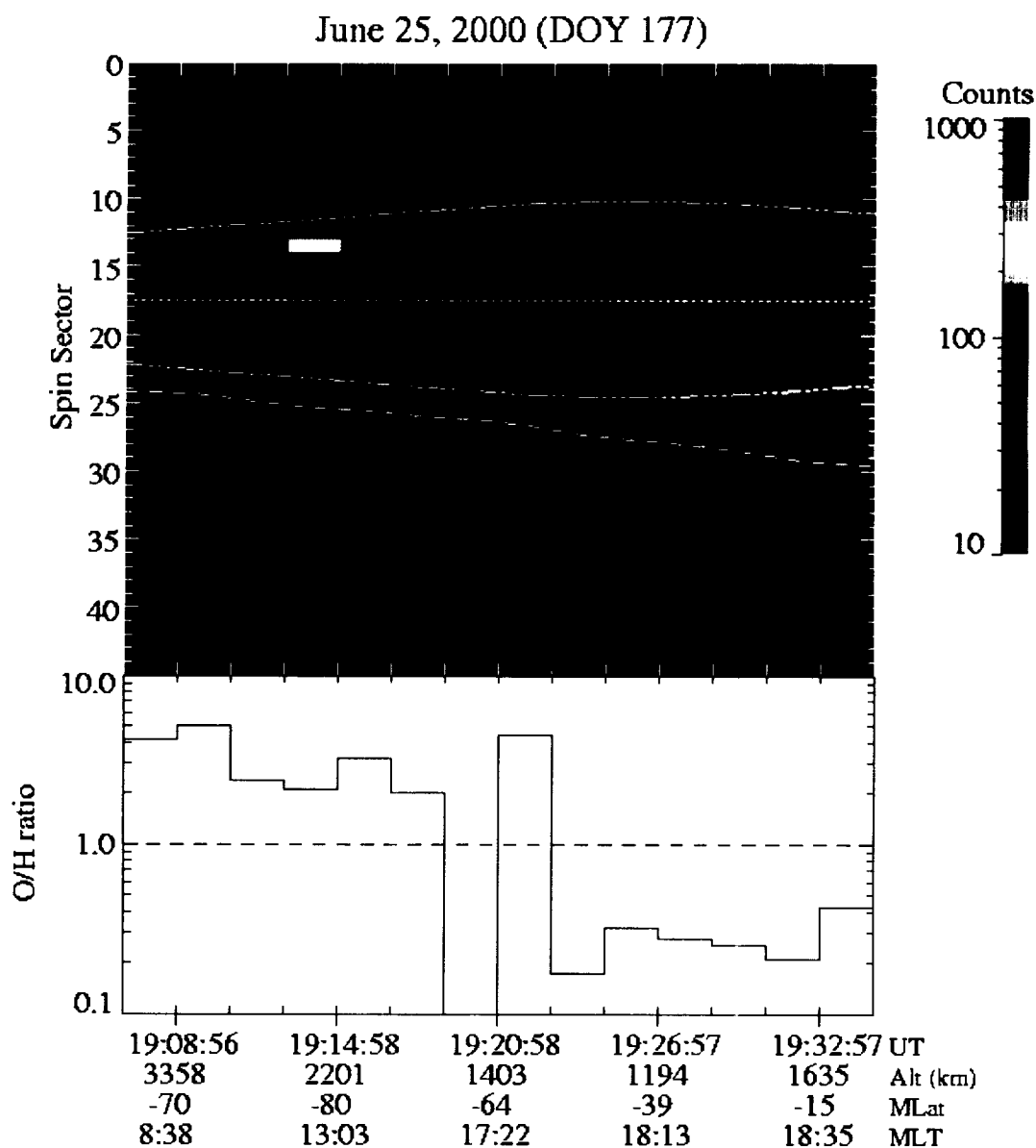


Figure 6. Perigee pass from June 25, 2000. Note the missing image between 1918:58 and 1920:58. At the time of this pass Kp was 2- ($A_p = 6$).

day. At the time of the pass Kp was 2 where it had been 3+ in the three-hour time interval (6-9 UT) before. Quick look AE was about 300 nT at the time. The $F_{10.7}$ index was 152 for July 31, which makes this day one of the quietist, in terms of solar activity, in the June-August time period. Between 0000 and 1000 UT on the 31st the solar wind density was between 4 and 7 cm⁻³ and the solar wind speed was between 400 and 450 km/s. The magnitude of the IMF remained less than about 8 nT but it turned and remained southward during the three hours before the IMAGE perigee pass. Could it be that these intense emissions are a result of a constant stirring of the magnetosphere for 3 or more hours?

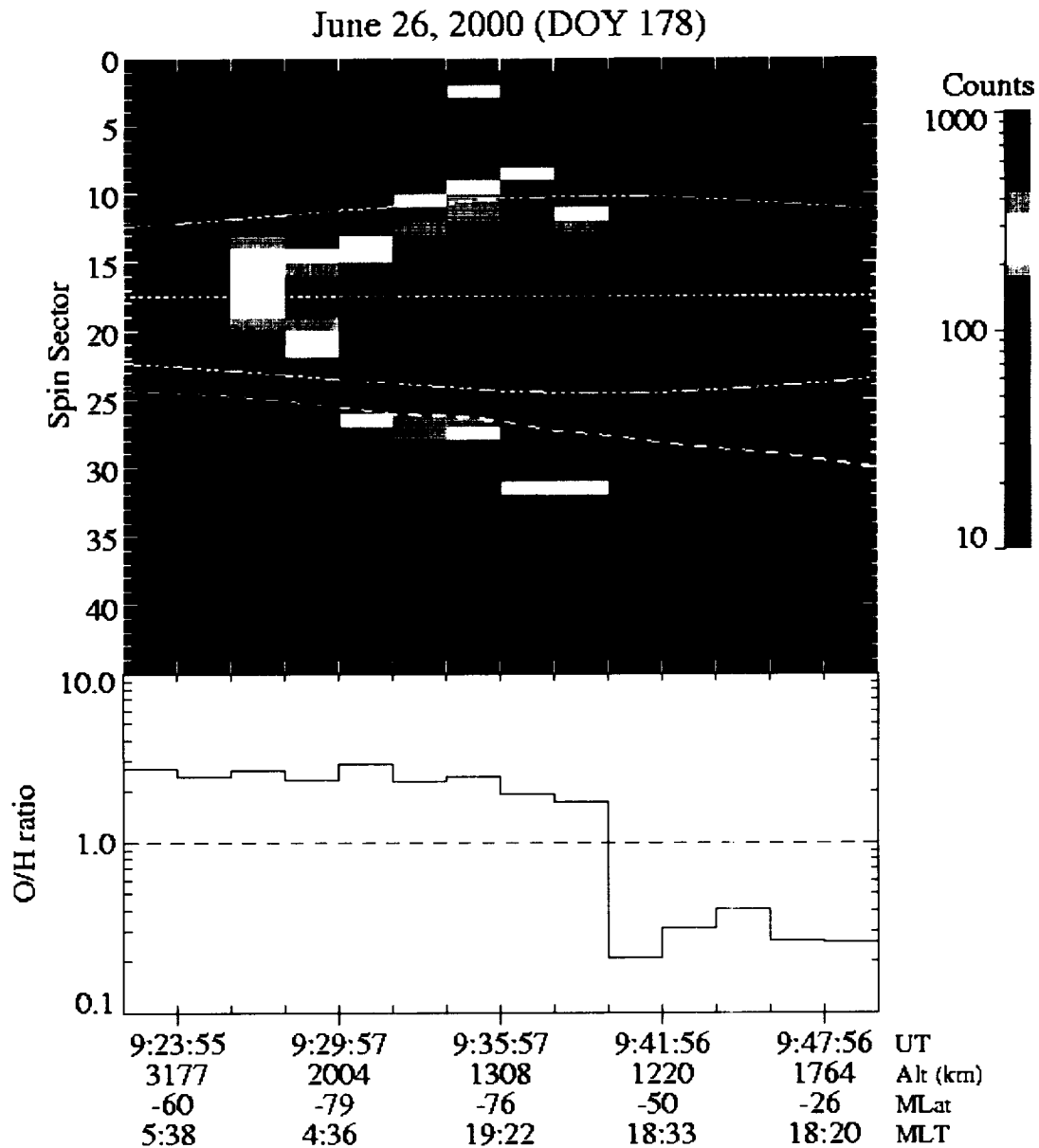


Figure 7. 1st Perigee pass from June 26, 2000. Kp at the time of this pass was 5 ($A_p = 48$).

Below I show a few additional examples to illustrate the trends discussed above. The first two are perigee passes from June 25th and 26th (see figures 6 and 7). The main thing to note in this pair of consecutive passes is the change in the overall intensity of the images from a value of 3088 total counts for June 25th to 72660 total counts for June 26th. Between the times of these two passes Kp changed from 2- to 5. Also visible in this data is when the stop voltage reduction took effect. From the instrument state tables the reduction during the June 25th pass occurred at 1920:56 UT and for the June 26th pass it occurred at 0937:55 UT.

The next pair of example passes comes from July 2, 2000 and are part of group 2. The total number of counts for the first of these passes was 38847 and for the second was 5078. The value of Kp was 1 for both of these passes. In terms of magnetic activity July 2nd was a very quiet day where Kp never got above 2-. The stop MCP voltage was reduced to 128 twice on the 2nd at 0757:40 and 2206:39 UT.

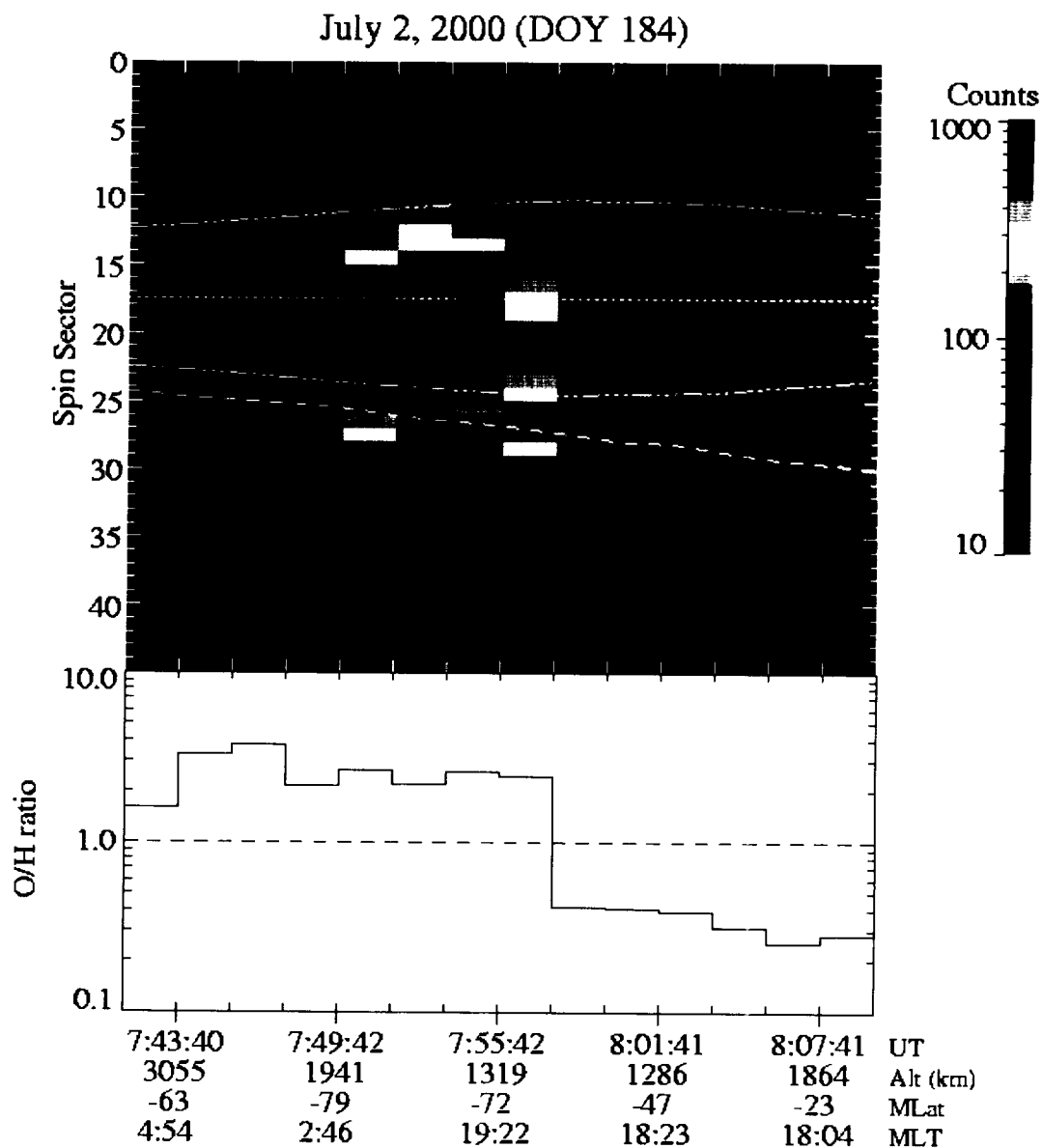


Figure 8. First perigee pass from July 2, 2000. Kp for this pass was 1 ($A_p = 4$).

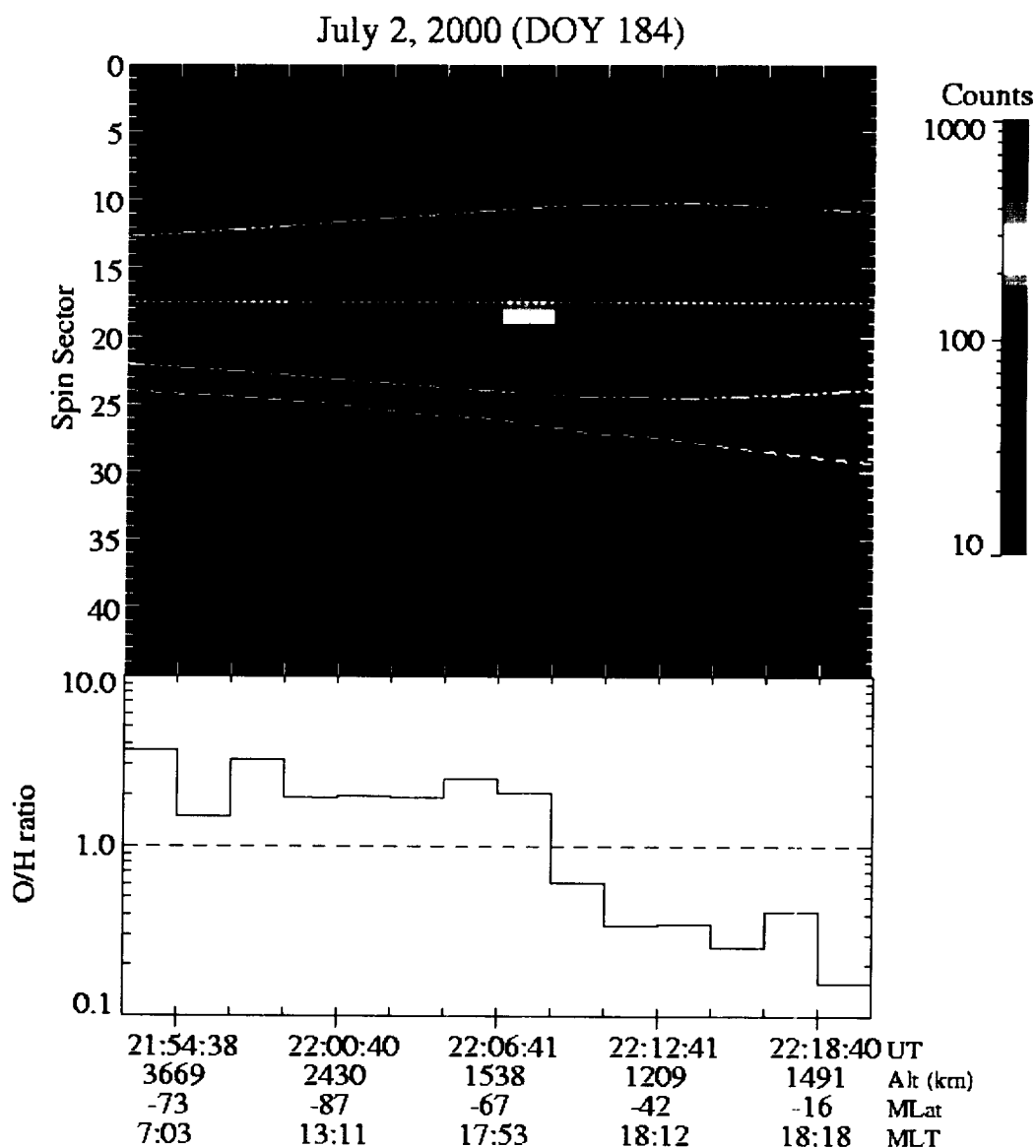


Figure 9. Second perigee pass from July 2, 2000. K_p for this pass was 1 ($A_p = 4$).

Finally I show a few examples of perigee passes from the August group whose behavior is significantly different from the passes of June and July. The first is shown in figure 10 and is the first pass from August 6th. The count total for this pass was 47584. Note the gradual reduction in the intensity of the images and the gradual reduction in the O/H ratio between the times 0734 and 0742 UT. According to the state table for this date the stop MCP voltage was 144 at the start of the pass and was reduced to 136 at 0735:52 UT, 135 at 0737:52 UT, and 134 at 0739:51 UT. The behavior seen in this pass seems to be consistent with what was seen earlier but spread out due to the stepwise reduction in the stop MCP voltage.

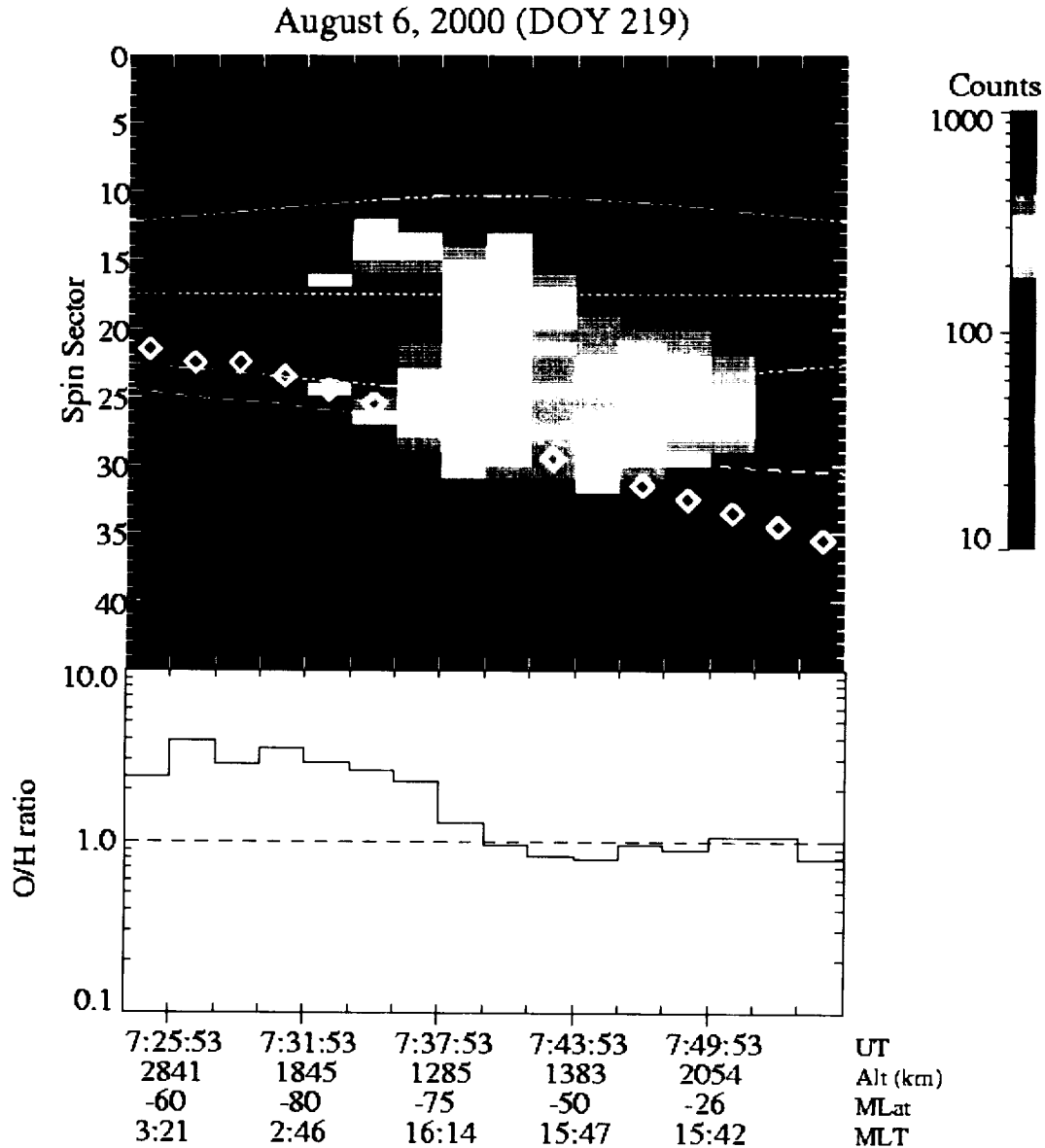


Figure 10. First perigee pass from August 6, 2000. K_p at the time of this pass was 2+ ($A_p = 9$).

The next perigee pass is from August 18th. In it one can clearly see the sun pulse (marked by the diamonds). Below is a list of stop MCP voltages and the times at which they took effect for times near this pass. The behavior of this value seems to be somewhat chaotic during this time interval. Note the changes in the stop MCP voltage that occur at 0414, 0416 and 0418 UT that are associated with the drop in the O/H ratio at about the same time. Note also the large fluxes coming from the anti-ram direction at spin sectors between 2 and 10. This signal is well separated from the earth and is not associated with the sun. This could be an edge on look through a region of high altitude emission.

231 03 37 42	1.39e+02
231 03 45 49	1.44e+02
231 03 47 51	1.40e+02

231 03 51 54	1.44e+02
231 03 53 56	1.39e+02
231 03 59 59	1.41e+02
231 04 02 00	1.44e+02
231 04 04 01	1.42e+02
231 04 14 01	1.44e+02
231 04 16 01	1.39e+02
231 04 18 01	1.34e+02
231 04 32 03	1.36e+02

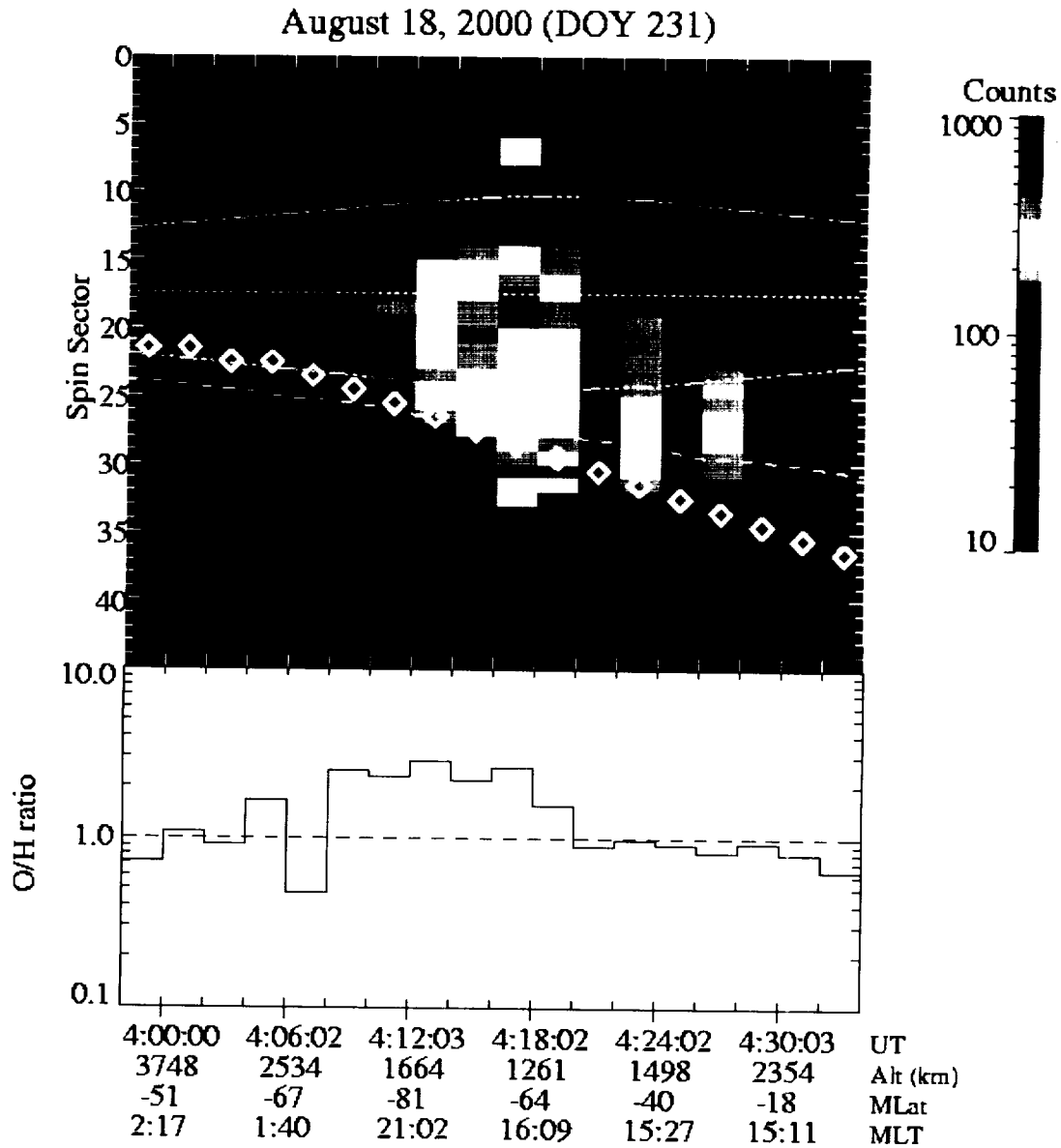


Figure 11. First perigee pass from August 18, 2000. Kp for this pass was 1+ (Ap = 5).

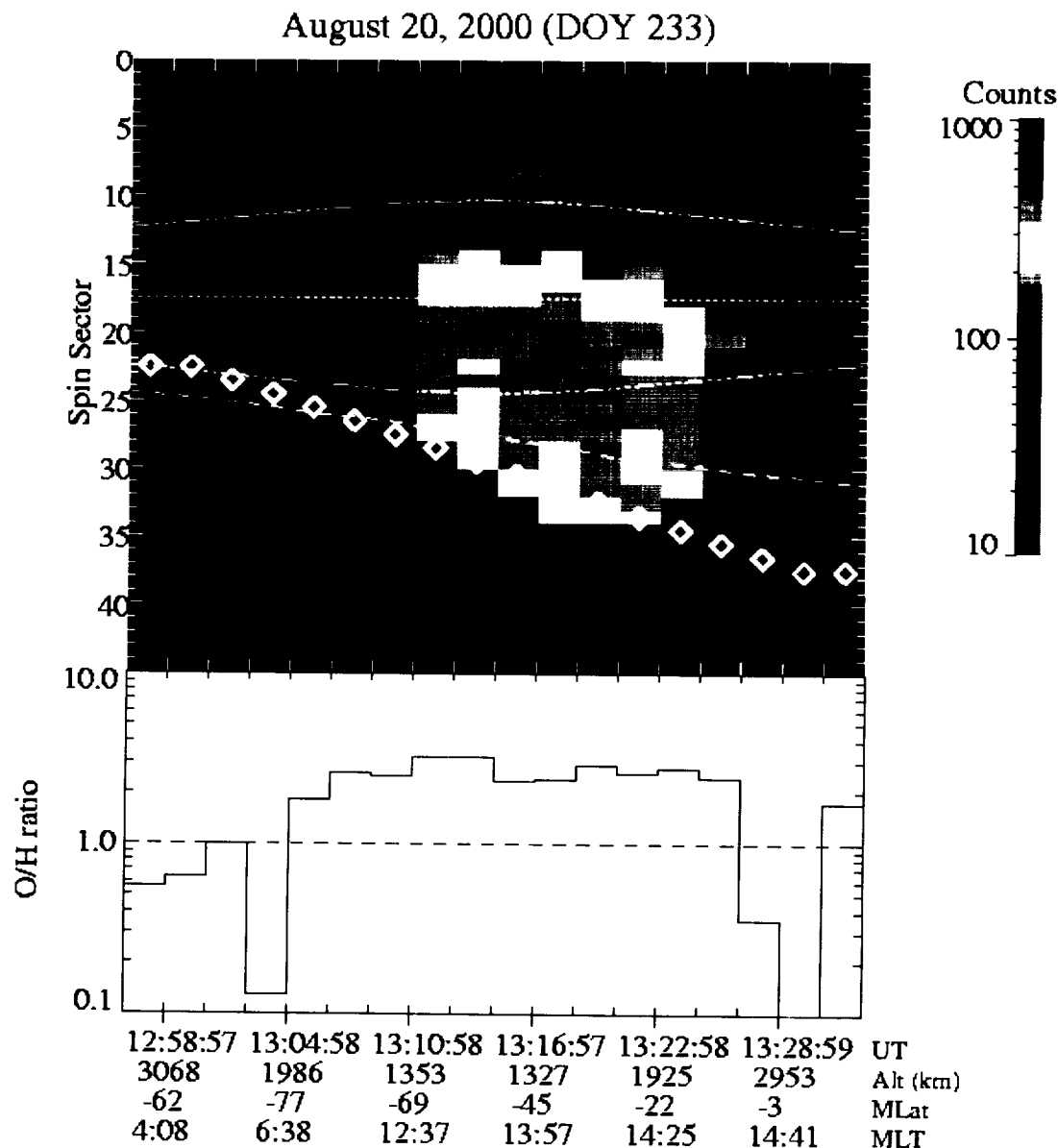


Figure 12. Perigee pass from August 20, 2000. Kp at the time of this pass was 1- ($A_p = 3$).

The last perigee pass shown here is that from August 20th shown in figure 12. The stop MCP voltage was set at 144 up until 1326:58 UT when it was reduced to 142. At 1328:58 UT it was further reduced to 139 and then increased to 142 at 1330:59. Through most of this pass the instrument was in its most sensitive mode. The picket fence pattern seen in the pre trailing limb signal (spin sectors 2-10) seems to be unrelated to changes in instrument state. There are a number of other examples of this type of behavior in the August 2000 data set. It is unlikely that a natural phenomena would have the same period as the spacecraft spin. Could this be an example of errors in data processing where counts are assigned to the wrong spin sectors?

B) Description of Progress on the Plasmasphere model.

Nothing new to report.

2. Current Problems.

There are no problems affecting the continuation of this project.

3. Work to be performed during the next quarterly reporting period.

After consultations with other team members I will proceed with plans for a paper.

4. Cost information.

The current contract value (options 0, 1, 2, and 3) is \$197182 with an end date of 31 Jan 2002.

(a) Total cumulative costs as of report date: \$133409

(b) Estimated cost to complete contract: \$63773

(c) Estimated percentage of completion of contract: 68%

(d) We are on tract to finish this portion of the overall project.

This project has been modified and divided into two subtasks. Subtask 01 covers the LENA instrument support work and subtask 02 is the plasmasphere-modeling project. The numbers above cover the total contract (subtasks 01 and 02).